УДК 524.386
PACS 97.80.Hn
DOI 10.24144/2415-8038.2020.48.78-91

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INFLUENCE OF STARSPOTS AND PULSATIONS ON DETERMINATION OF THIRD BODY ORBITAL PARAMETERS IN ECLIPSING BINARY SYSTEMS

Purpose. Defined the influence of starspots and pulsation of eclipsing binary components on the possibility of the third body determination in eclipsing binary systems and estimation of orbital parameters errors caused by such factors.
Methods. In this paper method of O-C diagrams was used to detect the eclipsing binary system period change caused by the presence of the third body. Monte Carlo simulations were used to estimate values of third body orbital parameters that correspond to obtained O-C diagrams. This method is compiled in «OCFit» software.
Results. Different cases of starspots and pulsation are considered. The precision of orbital parameters calculated for these cases.
Conclusions. Detached EB systems with spot are not sophisticated objects for 3^{rd} body detection. Contact EB systems with migrated spots are more complicated systems to search third bodies and detect their orbital parameters. In the case of EB system pulsation most precise results can be obtained with a long period of pulsations. Resolution of the light curve is very important to make good O-C diagram.
Keywords: variable stars, eclipsing binary systems, O-C diagram, starspots, pulsations.

Introduction

Eclipsing binary (EB) systems are objects of research in different aspects of astronomy, one of them is searching of third bodies in EB systems. For these purposes O-C diagram method is commonly used. In this paper, we will describe some factors that have an influence on the light curve minima shape of EB systems, and therefore on shape of O-C diagram too. Such factors are: presents of *spots* on EB component, or on both components and *pulsations* of EB system.

Our simulations are based on a light curves (LC) generated by PHOEBE software [1] based on well known Wilson & Devinney code described in work [2]. These LC will be extended for needed number of cycles, usually 5 or 10 year. Time shifts in LC caused by presence of 3^{rd} body will be added based on computation made in work [3, 4]. On the final stage other distortion factors mentioned above are also added to LC. Orbital elements of 3^{rd} body will be determined from O-C diagrams using Monte Carlo simulations by «OCFit» software described in [5].

In our simulation we use EB stars that are located near the north pole to get maximum data coverage.

Spots in EB Systems

In this section we will try to simulate O-C diagrams in ideal terrestrial conditions but under the influence of other non-terrestrial factors like starspots.

As we know the formation of starspots depends on the age of a host star, that's why we should separate our simulation for detached and contact EB systems. But before we start to simulate we need to know some general spot parameters for this EB systems. Its a radius of star spot, its temperature, and life cycle. Do the spot disappear after some short time or can be present on a host star for a relatively long time like 5-10 years? The spots migrate or not?

In work [6] authors have shown that intensity variations resulting from star-spots (not taking into account Wilson depressions) can introduce disturbances of up to ~ 0.01 day in the O-C residuals of contact binaries. Given the rapid evolutionary time-scales of spots (of the order of days) seen in recent Doppler images of the contact binary AE Phe [7] this may lead to explaining some of the observed jitter in the O-C curves of these objects. But in work [8], the effects of a Wilson depression seem to result in a scatter of only a few seconds in the O-C residuals, it seems unlikely that the Wilson depression will be a significant source of jitter for contact binaries. Such changes resulting from star-spots would be distinguishable from other mechanisms that cause period changes and it should still be possible to determine the orbital period accurately [8].

Several studies have indicated that spot on close binaries can have angular diameters from $10°$ to $40°$ which means that they will cover from 5 to 25% of the whole photosphere of the active components (e.g. [9, 10]). In most cases, active component can have one or two giant spots. It is also argued that such spots can remain on a surface from a few years to even ten years [6].

For a estimation of maximum effect caused by the star spot, it is assumed that in our simulations spots are located on equator of each component. According to [6] spots with angular diameter less then $10°$ cause negligible shifts of the light minimum of the primary eclipse. Therefore we will not consider with spots smaller then $10°$ (see Fig. 1).

Furthermore, the spots on secondary component always remain visible during the primary eclipse, while the spots on primary do not. As a result, the spots on primary cause a significantly greater photometric perturbation to the light curve than the spots on secondary component.

In paper [6] authors also showed that unlike real orbital period changes, non-migrating star spots cannot cause permanent slopes in the O-C diagrams. But the O-C differences caused by long-lived migrating spots can be expected to be periodic.

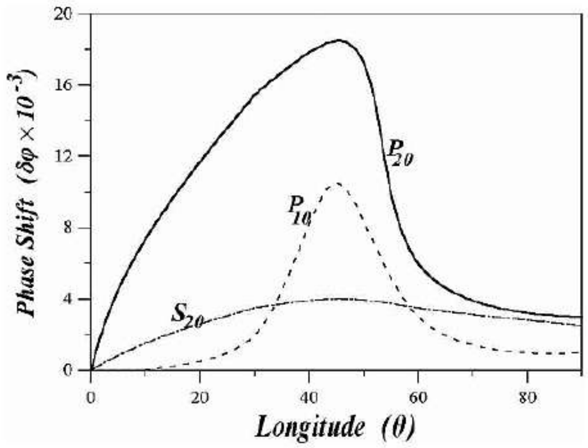


Figure 1: Phase shift $\delta\varphi(\theta)$ of the primary eclipse of a contact binary similar to AB And. Curves labelled by ”P” correspond to a spot on the primary, while ”S” refers to a spot on the secondary component. [6].

Detached EB Systems

Tidal interactions force most of these stars to rotate synchronously with their orbital motions. The rapid rotation combined with deep convection envelopes produces a variety of magnetic activity phenomena including starspots in these stars.

Brightness variations due to starspots can be observed in detached EB only during primary total eclipses when the luminous hot components are hidden. Therefore, because of synchronized rotation, only one hemisphere of the cool stars can be observed and the photometric data collected are less detailed than for other spotted binaries [11].

For detached eclipsing binary systems spots with radius from 5° to 25°are usually typical, we can find such systems in many publications like e.g. [12] or in publications about spots in RSCVn binaries systems (e.g. [13–15]). Objects with spots migrations are very rarely observed, so we will not consider such a case. Model of detached EB system is presented on Figure 2, the main parameters of this system are listed in the Table 1.

As we mentioned above, spots with a radius less then 10° do not have a big influence on O-C diagram. So, we will consider how starspot located on stars equator (colat=90°, lon=0°) with radius $r_{spot} = 15°$ and $r_{spot} = 25°$ affect the O-C diagram. There is also a difference in a hot and cold spot. The hot spot will have $T_{spot} = 1.2$, where T_{spot} is the ratio between the temperature of the spot and the local temperature of the underlying photosphere, the cold spot will be defined as $T_{spot} = 0.8$. On Figure 3 we can see how hot and cold spots affect the shape of the minima. Mainly primary minima are changing their shape under the influence of spots.

The final O-C diagrams for all four cases are presented in Figure 4. Looking only on O-C diagram we can't clearly see the difference. Only when we fit these O-C diagrams by MCMC method results are getting clearer. Final solutions of fitting are presented in Table 2. Analysing χ^2 value of 4 cases we can state that case of spot with parameters $T_{spot} = 1.2$ and $r_{spot} = 25°$ is fitted the best. The precision of fit depends on the accuracy of minima determination that can vary depending on the method we used. In case of a spot with parameters $T_{spot} = 1.2$ and $r_{spot} = 25°$ precision of minima determination was almost the same for primary and secondary minima.

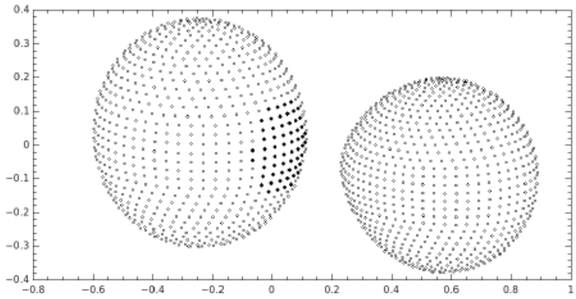
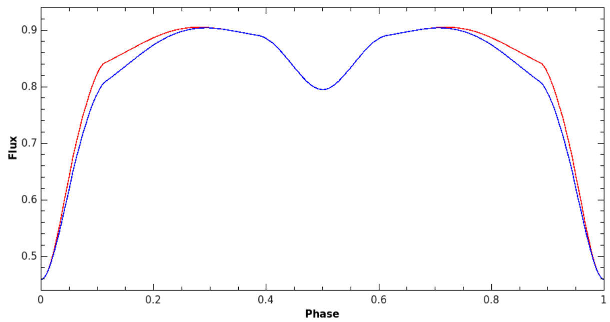


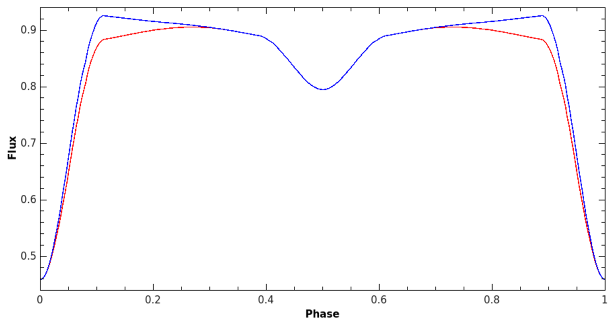
Figure 2: Model of detached EB system with spot (colat=90°, colon=0°) in plane of sky view at phase 0.15.

Table 1: Basic parameters of detached binary system presented on Figure 2. HJD0 is a origin of the ephemeris; P - orbital period of EB system; SMA - semi-major axis; RM - mass ratio; VGA - centre of mass velocity, INCL - inclination

HJD0(day)	2451852.3783
P(day)	1.42834
SMA ($R_\odot$)	1.000
RM	0.432
VGA (km/s)	0
INCL (°)	77.690

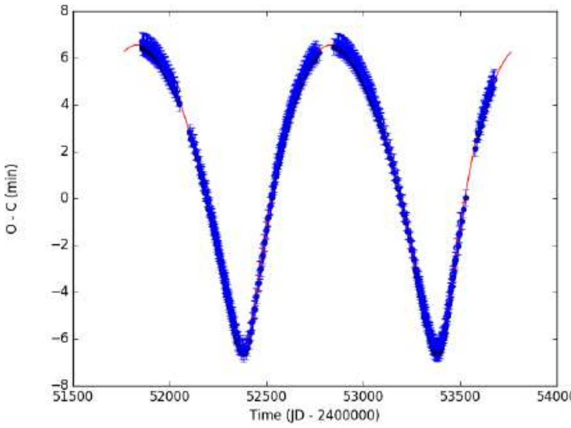


(a) Spot with $T_{spot} = 0.8$

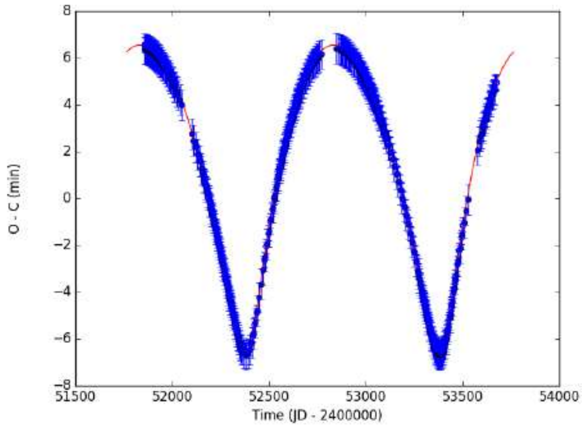


(b) Spot with $T_{spot} = 1.2$

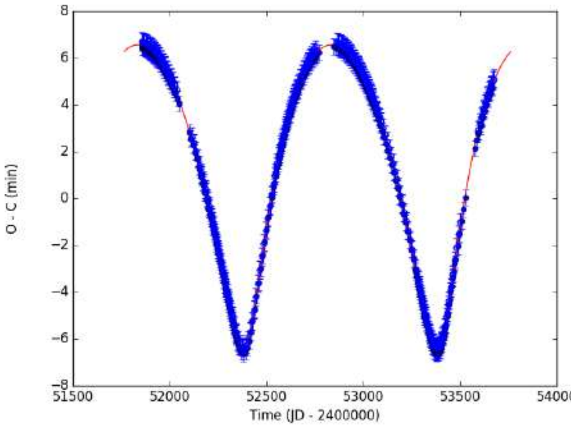
Figure 3: Spot on primary component with different temperature and radius. Blue line - spot radius 25°, red line - spot radius 15°



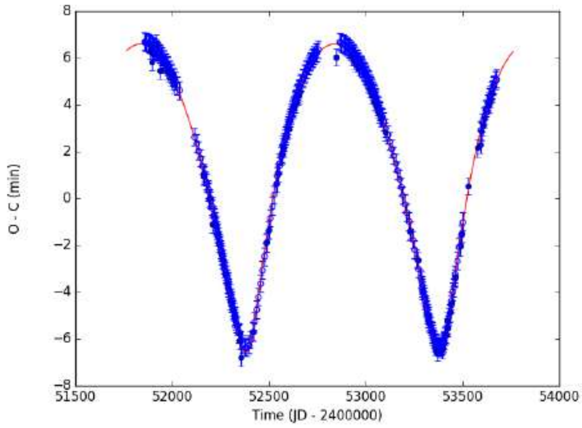
(a) O-C diagram with $r_{spot} = 15, T_{spot} = 1.2$



(b) O-C diagram with $r_{spot} = 25, T_{spot} = 1.2$



(c) O-C diagram with $r_{spot} = 15, T_{spot} = 0.8$



(d) O-C diagram with $r_{spot} = 25, T_{spot} = 0.8$

Figure 4: O-C diagram for EB system with different r_{spot} and T_{spot}. Red line - fit with MCMC method, correspond to values in Table 2. Filled circles are primary minima, not filled circles - secondary minima.

Table 2: Orbital parameters of 3^{rd} body for detached EB system with different spot parameters r_{spot} and T_{spot}. P – orbital period of eclipsing pair, T_0 – initial minimum, P_3 - orbital period of the 3^{rd} body, t_{03} – pericenter passage, $a \sin i_3$ – projected semi-major axis of the orbit, e_3 – eccentricity, ω_3 – the longitude of the periastron, $f(M_3)$ – the mass function, χ^2 – sum of squares of the best fit, χ^2/n – reduced sum of squares (n – number of data points), errors are given in parenthesis.

Solution	Original	r_{spot}=25° T_{spot}=1.2	r_{spot}=25° T_{spot}=0.8	r_{spot}=15° T_{spot}=1.2	r_{spot}=15° T_{spot}=0.8
P [days]	1.42834	fixed	fixed	fixed	fixed
T_0 [HJD]	2451852.3783	fixed	fixed	fixed	fixed
P_3 [days]	1000	1000(1)	1000.0(7)	1000(1)	1000.8(9)
t_{03} [HJD]	2451400	2451397(3)	2451397(1)	2451396(2)	2451396(2)
$a \sin i_3$ [AU]	0.797	0.801(2)	0.803(3)	0.806(4)	0.802(3)
e_3	0.54	0.552(3)	0.559(4)	0.572(5)	0.563(3)
ω_3 [°]	288	287.2(8)	287.1(6)	286.9(8)	286.9(7)
$f(M_3)$ [$M_\odot$]	–	0.0685(7)	0.0690(7)	0.0697(10)	0.0691(7)
χ^2	–	7.326	35.990	30.227	39.209
χ^2/n	–	0.0127	0.0654	0.0767	0.0993

It was mentioned above that spot on secondary component do not have a big influence on minima shape, so we will not consider here this option.

As a conclusion we can say that detached EB systems with spot are not sophisticated objects for 3^{rd} body detection. In case of bigger then 25° spots on the surface it is advisable to cut off from the top the height of primary (or secondary) minima to get better fit and to determine the time of minima more precisely.

Contact EB Systems

Contact binary stars occur relatively often among binaries (95% of eclipsing binary variables in the solar neighbourhood) [16]. A contact binary system consists of two dwarf stars, most often from the F, G, and K spectral classes, that are surrounded by a common convective envelope. The orbital period distribution peaks in the 8 to 12 hour range. Most systems, though not all, have orbital periods between 0.2 and 1.0 days [17, 18]. While the masses of the two component stars of a contact binary are typically unequal, the two stars usually have approximately equal surface temperatures due to the effects of mass and energy transfer between the components via a common convective envelope [19]. Eclipsing contact binaries are often referred to as W UMa systems in honor of the prototype [20].

The components of such a contact binary rotate very rapidly in spite of their old ages ($v\ sin\ i \sim 100 - 200\ km\ s^{-1}$) as a result of spin-orbit synchronisation due to strong tidal interactions between the stars [11].

Many contact binaries show signs of stellar activity, presumably because the component stars are rapid rotators with deep convective zones. A study of the contact binaries with Doppler imaging technique reveals that both components can be covered by cool starspots, with a tendency for the primary to be more active than the secondary [7, 21, 22].

This makes contact binaries excellent laboratories in which to investigate the temporal variations and evolution of stellar spots, in part because the timescales of the variations are shorter than in other types of binary and single stars. However, the shortest among these timescales can be problematic to study using groundbased observatories because they are comparable to the length of an Earth night.

In [6] authors noted that the migration of starspots on the surface(s) of the constituent stars in short-period binaries, especially contact binaries, could affect measurements of eclipse times and thereby mimic changes in the orbital period [20].

Model of contact EB system with spot is presented on Figure 5, orbital parameters can be found in Table 3.

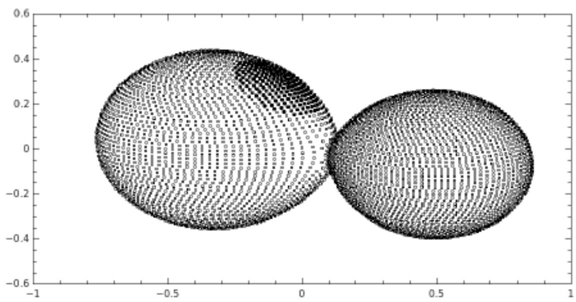
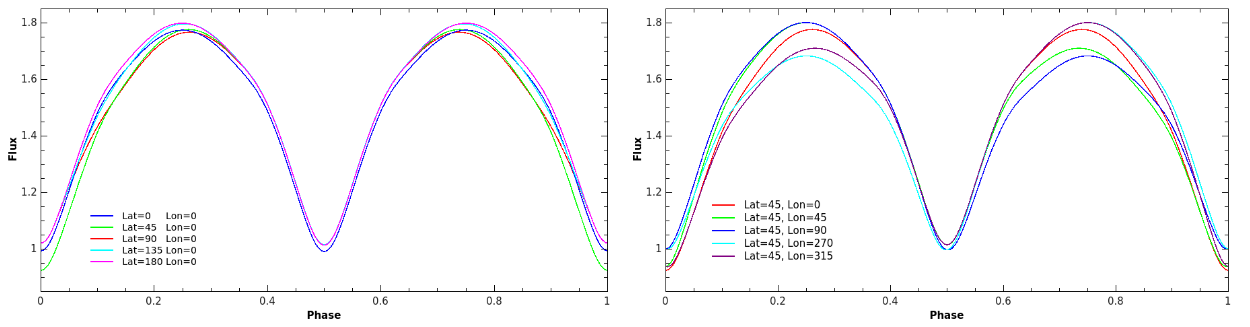


Figure 5: Model of contact EB system with spot (colat=45°, colon=0°) in plane of sky view at phase 0.15.

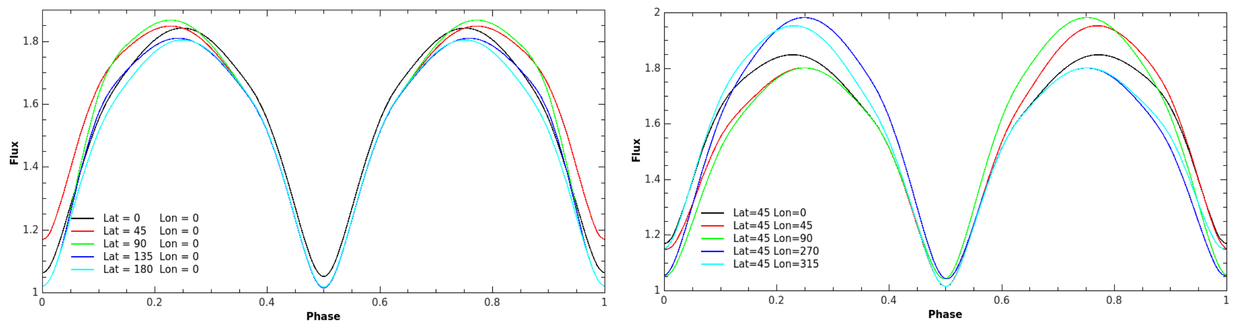
Table 3: Baisic parameters of contact binary system presented on Figure 5. HJD0 is a origin of the ephemeris; P - orbital period of EB system; SMA - semi-major axis; RM - mass ratio; VGA - centre of mass velocity, INCL - inclination

HJD0(day)	2451852.3783
P(day)	1.42834
SMA ($R_{\odot}$)	1.76
RM	0.67
VGA (km/s)	4.70
INCL (°)	79.50



(a) LC with spot on different colatitude and longitude = 0°. (b) LC with spot on different longitude and colatitude = 45°.

Figure 6: LC of contact binary system with ”cold” spot ($T_{spot} = 0.8\ T_{surf}$) on primary component at different positions



(a) LC with spot on different colatitude and longitude = 0°. (b) LC with spot on different longitude and colatitude = 45°.

Figure 7: LC of contact binary system with ”hot” spot ($T_{spot} = 1.2\ T_{surf}$) on primary component at different positions

Light curve from such EB system will be subjected to changes depending on the position of the spot, such changes are partially presented on Figure 6, 7. Analyzing these data we can conclude that the most noticeable changes in LC are caused by changes of position in longitude of a starspot on the primary component of contact binary EB system. If we change spot position only in colatitude and leave longitude equal to 0°, we will observe only variation of primary minima shape and depth. On the other hand if we make colatitude constant (colatitude = 45°, see Figures 6, 7) and change longitude of spot then in addition to the primary minimum part of the LC between two minima will vary too. As it can be expected ”hot” spot has a greater contribution to changes in LC than ”cold” spot (see Fig. 6b vs 7b).

From previous results with detached EB system, we already know that smaller and colder spot adds more uncertainty to the definition of orbital elements of 3^{rd} body available in EB system. We can expect the same results with contact EB systems. So let us define an influence of the spot presence on primary and secondary EB components and spot migration. This two aspects can be often found in contact and overcontact systems.

For simulation of O-C diagram with two spots in EB system we locate the spot on secondary component at $lon = 180°$, $colat = 45°$ to make it visible to the observer. Radius of the spot on secondary component is $r_{spot_s} = 35°$, temperature is $T_{spot_s} = 0.8\ T_{surf}$. The results of orbital parameters of 3^{rd} body determination for this case are presented in third column of Table 4.

For simulation of O-C diagram with migrated spot over primary component of EB system we should define a parameters of the spot migration. According to [6] rotation period of starspot differs from P_{eq} by:

$$\Delta P = P_\lambda - P_{eq}, \quad (1)$$

where P_{eq} is the equatorial period of rotation ($P_{eq} = P_0$), and P_λ is a period of starspot rotation equal to:

$$P_\lambda = P_{eq} \cdot (1 - k \cdot \sin^2 \lambda)^{-1}, \quad (2)$$

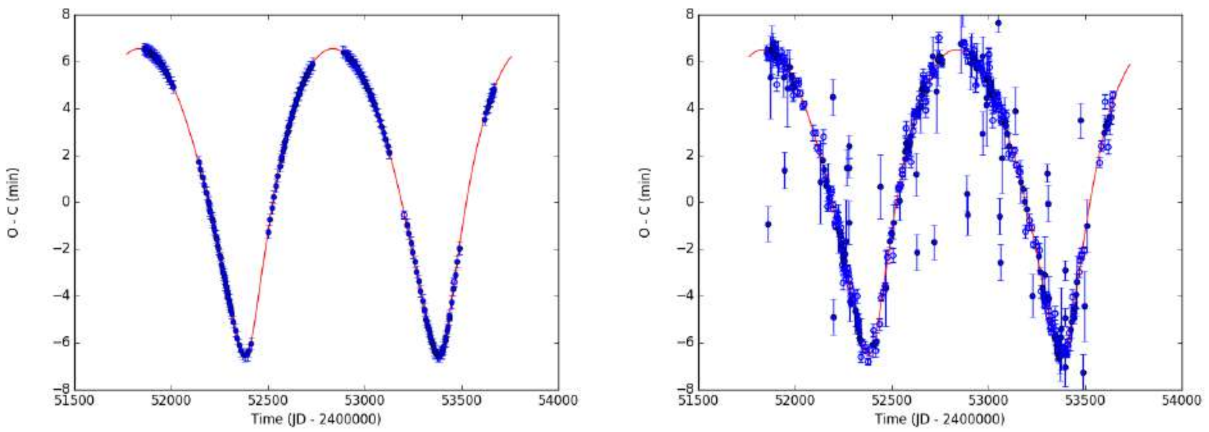
in equation (2) k is a coefficient of differential rotation. For close binaries observation have indicated a range between $k \approx 6 \times 10^{-4}$ and 0.18 with mean value $\bar{k} = 3 \times 10^{-2}$ [9]. At the end of each orbital cycle, a starspot will shift in longitude by:

$$\delta\theta = 2\pi \frac{\Delta P}{P} \quad (3)$$

If we calculate this value for our EB system with period $P = 1.42834$ which has spot on latitude $\lambda = 45°$ and mean value of $\bar{k} = 3 \times 10^{-2}$, we will get $\delta\theta = 5.4798°$ or $\delta\theta \sim 5.5°$. So spot with such parameters will do a full revolution in ~ 65.5 cycles or in our case this is equal to 93.5 days. To simplify the process of simulation we take an integer number of $\delta\theta = 6°$ in such case the spot will do a full revolution in 60 cycles or in 85.7 days.

Large spots causing prominent light curve minima apparently can survive for many years, despite differential rotation, and form centres of activity, or active longitudes [11]. Polar spots are found to have lifetimes of over a decade [23]. Our simulation of 3^{rd} body is made on 5 years time interval so lets define that our spot lifetime is also 5 years.

Last question that we need to know is a radius of a spot. Lets consider a case with a spot radius 35° because a bigger spots are more typical for this type of EB systems.



(a) O-C diagram for ideal condition.

(b) O-C diagram for EB system with spot.

Figure 8: O-C diagram for contact EB system with (b) and without (a) migrated spot. Red line - fit with MCMC method, correspond to values in Table 4. Filled circles are primary minima, not filled circles - secondary minima.

From Figure 8 we can clearly see how migrated spot reduce precisions of minima exact time detection and in some cases, we even got point that does not fit in our O-C diagram. This means that these points are faults. Migrated spots are the most difficult cases for precise definition time of minima, make O-C diagram and define orbital parameters of 3^{rd} body. Fitted parameters of orbit and χ^2 values of fit are presented in Table 4.

Pulsations in EB Systems

Pulsation in eclipsing binary systems can be observed in Algol-type binaries, the so-called oEA stars (oscillating EA stars). The oEA stars are mass-accreting main sequence A/F-type components in semidetached Algol-type eclipsing binary systems showing δ Sct - like pulsation [24]. The period of pulsation in such systems can vary from 20 to 300 minutes (see e.g [25],

Table 4: Orbital parameters of 3^{rd} body for contact EB system with two spots and migrated spot. Spot parameters $r_{spot} = 35°$, $T_{spot} = 0.8\,T_{surf}$. For description of parameters see Table 2

Solution	Original	no spot	two spots	migrated spot
P [days]	1.42834	fixed	fixed	fixed
T_0 [HJD]	2451852.3783	fixed	fixed	fixed
P_3 [days]	1000	999.7(8)	999(1)	1000(1)
t_{03} [HJD]	2451400	2451400(2)	2451402(2)	2451398(4)
$a \sin i_3$ [AU]	0.797	0.799(3)	0.799(3)	0.764(3)
e_3	0.54	0.541(4)	0.532(5)	0.541(2)
ω_3 [°]	288	288.1(7)	288.5(8)	287(1)
$f(M_3)$ [$M_\odot$]	–	0.0681(8)	0.0683(9)	0.0666(7)
χ^2	–	0.614	6.547	2478.629
χ^2/n	–	0.0283	0.0719	6.1200

[26]).

In work [25] relation for period of pulsation is given as:

$$P_{pul} = 0.031(4) + 0.009(1)P_{orb}. \quad (4)$$

This relation is based on observation of δ Sct stars in all known close binaries systems (Detached, Semi-detached, unclassified). Coefficient of correlation for this relation is $r = 0.62$.

To determine how the pulsations affect the O-C diagram and 3^{rd} precision of orbital elements we will consider three cases of detached EB systems with a different period of pulsations: 30, 150, 300 minutes.

To define the precise time of minima with pulsation presence it is very important to have a high rate of observation per some time interval (or per LC). Until now we use synthetic LC generated by PHOEBE with sample rate 300 points per period. That was fully enough to precisely determine the time of the minima, but such rate is not enough for pulsations study.

To determine what sample rate should we use, let us check how the precision of primary minima is changed in detached EB system with added pulsations with parameters – period $P_{pus} = 30$ min and amplitude $A_{puls} = 0.02$. Three examples of same minima fitted in sample rates 300, 600 and 900 points per LC are presented on Figure 9. If we have more than 900 points per LC then the precision of minima determination is slightly increasing to value 0.001 of a day. With the increase of sample rate, time of calculation also greatly increases, therefore the value of 900 points per LC is the best choice.

Third body orbit parameters determined in detached EB system with pulsation with a period of 30, 150 and 300 minutes are presented in Table 5. As we can see from a table, the most precise determination of orbit parameters corresponds to pulsation with the longest period. Vice versa most inaccurate parameters of orbit determination correspond to the shortest period. A short period of pulsations can't make it impossible to determine the precise time of minima, and as we show above it is also very important what resolution of LC do we have.

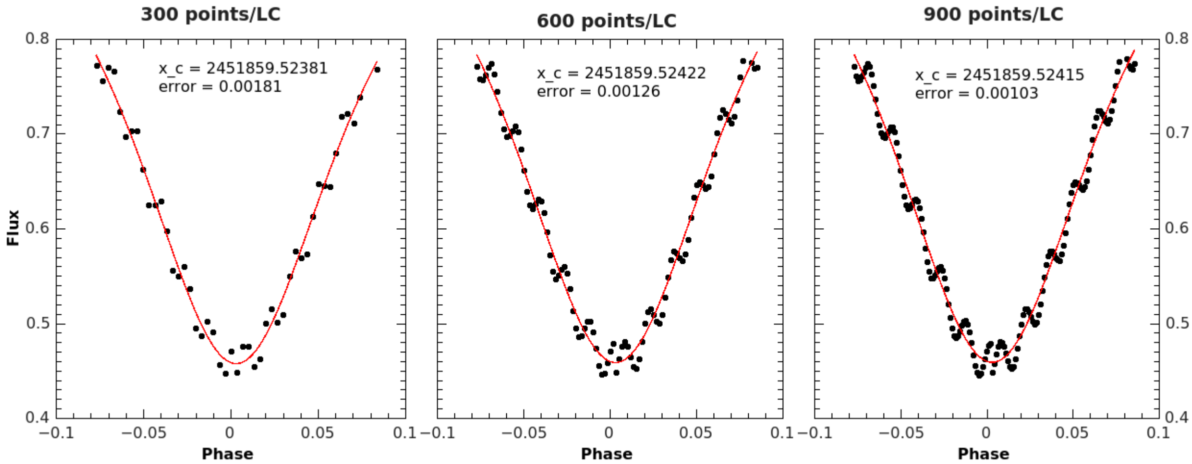


Figure 9: Different sample rate and precision of primary minima determination. Black point are data from LC, red line - fitted minima.

Table 5: Orbital parameters of 3^{rd} body for detached EB system with pulsations. For description of parameters see Table 2

Solution	Original	Pulsations P_{puls}=30 min	Pulsations P_{puls}=150 min	Pulsations P_{puls}=300 min
P [days]	1.42834	fixed	fixed	fixed
T_0 [HJD]	2451852.3783	fixed	fixed	fixed
P_3 [days]	1000	1000(7)	1002(8)	1000(7)
t_{03} [HJD]	2451400	2451408(16)	2451390(19)	2451399(19)
$a \sin i_3$ [AU]	0.797	0.778(19)	0.813(19)	0.807(19)
e_3	0.54	0.431(29)	0.600(28)	0.569(30)
ω_3 [°]	288	291(5)	285(5)	288(5)
$f(M_3)$ [$M_\odot$]	–	0.0628(47)	0.0715(52)	0.0700(52)
χ^2	–	8.519	2.778	0.802
χ^2/n	–	0.0184	0.0069	0.0019

Conclusion

We made a review of starspots and pulsation influence on determination of 3^{rd} body orbital parameters.

In case of starpsot presence on the surface of EB system components we separate our simulation for detached and contact binary systems. First case is not so sophisticated systems for 3^{rd} body detection, even when spot is available on the components of EB high precision of detected orbital elements can be achieved. For these case we also compare how hot and cold spots affect on the precision of 3^{rd} body determination. As the result the hot spots have less influence on 3^{rd} body orbit determination.

Second case with contact EB can represent more sophisticated examples of bigger starspots of EB components and several starspots at the time. This case more complicated and precision of orbital elements is reduces.

Pulsation of EB systems is the most complicated case for 3^{rd} body detection. In this situation is very important to achieve high sample rate to determine exact time of minima from light curve. As it can be seen from Table 5 biggest differences with original orbital elements of 3^{rd} body are observed in case of short period pulsations.

Such results are expected, but in this paper wee made orbital elements accuracy analysis. Also larger samples studies are needed to statistically confirm our results.

REFERENCES

[1] Prša, A., Zwitter, T. (2005), ”A Computational Guide to Physics of Eclipsing Binaries. I. Demonstrations and Perspectives”, The Astrophysical Journal, V. 628, pp. 426 – 438.

[2] Wilson, R. E., Devinney, E. J. (1971), ”Realization of Accurate Close-Binary Light Curves: Application to MR Cygni”, The Astrophysical Journal, V. 166, p. 605.

[3] Irwin, J. B. (1952), ”The Determination of a Light-Time Orbit.”, The Astrophysical Journal, V. 116, p. 211.

[4] Irwin, J. B. (1959), ”Standard light-time curves”, The Astrophysical Journal, V. 64, p. 149.

[5] Gajdoš, P., Parimucha, Š. (2019), ”New tool with GUI for fitting OC diagrams”, Proceedings of the 50th Conference on Variable Stars Research, held November 30 - December 2 2018 in Brno, Czech Republic, 2018, Ed. R. Kocián, V. 197, p. 71.

[6] Kalimeris, A., Rovithis-Livaniou, H., Rovithis, P. (2002), ”Starspots and photometric noise on observed minus calculated (O-C) diagrams”, Astronomy&Astrophysics, V. 387, pp. 969 – 976.

[7] Barnes, J. R., Lister, T. A., Hilditch, R. W., et.al. (2004), ”High-resolution Doppler images of the spotted contact binary AE Phe”, Mon. Not. of the Royal Ast. Soc., V. 348, pp. 1321 – 1331.

[8] Watson, C. A., Dhillon, V. S.(2004), ”The effect of star-spots on eclipse timings of binary stars”, NATO Advanced Science Institutes (ASI) Series C, V. 319, p. 377.

[9] Hall, D. S., Busby, M. R. (1990), ”Starspot Lifetimes”, Proceedings of the NATO Advanced Study Institute on Active Close Binaries, held in Kusadasi, Turkey, September 11-22, 1989. Editor: Cafer Ibanoglu, Publisher: Kluwer Academic Publishers, Dordrecht, The Netherlands, Boston, V. 319, p. 377.

[10] Guinan, E. F., Giménez, A. (1993), ”Magnetic Activity in Close Binarie”, ”The Realm of Interacting Binary Stars”. Editor: Sahade, J. and McCluskey, G. E. and Kondo, Y., Publisher: Springer Netherlands, p. 51 – 110.

[11] Berdyugina, S. V. (2005), ”Starspots: A Key to the Stellar Dynamo”, Living Reviews in Solar Physics, V. 2, Issue 1, p.62.

[12] Liakos, A., Zasche, P., Niarchos, P. (2011), ”A comprehensive study of six Algol type binaries”, New Astronomy, V. 16, Issue 8, pp.530 – 538.

[13] Roettenbacher, R. M., Harmon, R. O., Vutisalchavakul, N., et.al. (2011), ”A Study of Differential Rotation on II Pegasi via Photometric Starspot Imaging”, The Astronomical Journal, V. 141, No. 4, p.138.

[14] Kővári, Z., Korhonen, H., Kriskovics, L., et.al. (2012), ”Measuring differential rotation of the K-giant ζ Andromedae”, Astronomy & Astrophysics, V. 539, p.A50.

[15] Kozhevnikova, A. V., Alekseev, I. Y. (2015), ”Long-term spottedness variations of 16 RS CVn stars”, Astronomy Reports, V. 59, pp.937 – 951.

[16] Rucinski, S. M. (1998), ”Contact Binaries of the Galactic Disk: Comparison of the Baade’s Window and Open Cluster Samples”, The Astronomical Journal, V. 116, No. 6, pp.2998 – 3017.

[17] Maceroni, C., van't Veer, F. (1996), "The properties of W Ursae Majoris contact binaries: new results and old problems.", Astronomy & Astrophysics, V. 331, pp.523 – 531.

[18] Paczyński, B., Szczygieł, D. M., Pilecki, B., et.al. (2006), "Eclipsing binaries in the All Sky Automated Survey catalogue", Mon. Not. of the Royal Ast. Soc., V. 368, pp. 1311 – 1318.

[19] Lucy, L. B. (1968), "The Structure of Contact Binaries", Astrophysical Journal, V. 151, p. 1123.

[20] Tran, K., Levine, A., Rappaport, S., et.al. (2013), "The Anticorrelated Nature of the Primary and Secondary Eclipse Timing Variations for the Kepler Contact Binaries", Astrophysical Journal, V. 774, p. 81.

[21] Maceroni, C., Vilhu, O., van't Veer, F., et.al. (1994), "Surface imaging of late-type contact binaries I: AE Phoenicis and YY Eridani", Astronomy & Astrophysics, V. 288, p.529 – 537.

[22] Hendry, P. D., Mochnacki, S. W. (2000), "Doppler Imaging of VW Cephei: Distribution and Evolution of Starspots on a Contact Binary", Astrophysical Journal, V. 531, pp. 467 – 493.

[23] Hussain, G. A. J. (2002), "Starspot lifetimes", Astronomische Nachrichten, V. 323, pp. 349 – 356.

[24] Rodríguez, E., García, J. M., Costa, V., et. al. (2010), "δ Sct-type pulsations in eclipsing binary systems: Y Cam", Mon. Not. of the Royal Ast. Soc., V. 408, pp. 2149 – 2162.

[25] Liakos, A., Niarchos, P. (2017), "Catalogue and properties of δ Scuti stars in binaries", Mon. Not. of the Royal Ast. Soc., V. 465, pp. 1181 – 1200.

[26] Mkrtichian, D. E., Kim, S.-L., Rodríguez, E., et. al. (2007), "The oEA Stars", "Solar and Stellar Physics Through Eclipses", ASP Conference Series, proceedings of the conference held 27-29 March, 2006 at Ankara University, ÖRSEM Campus, Side, Antalya, Turkey. Edited by O. Demircan, S. O. Selam, and B. Albayrak. San Francisco: Astronomical Society of the Pacific, Vol. 370, p.194

Стаття надійшла до редакції 2.10.2020

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ВЛИЯНИЕ ПЯТЕН И ПУЛЬСАЦИЙ НА ОПРЕДЕЛЕНИЕ ЕЛЕМЕНТОВ ОРБИТЫ ТРЕТЬЕГО ТЕЛА В ЗАТЕМННО ДВОЙНЫХ СИСТЕМАХ

Определено влияние звездных пятен и пульсаций компонентов затменно-двойных систем на возможность обнаружения третьего тела в этих системах и оценку погрешностей орбитальных параметров третьего тела вызванных такими факторами. В этой работе использован метод O-C диаграмм для выявления изменения периода затменно-двойных систем, вызванных наличием третьего тела в системе. Моделирование Монте-Карло были использованы для оценки значений орбитальных параметров третьего тела, которые соответствуют полученным O-C диаграммам. Этот метод заложен в программное обеспечение «OCFit». В работе рассматриваются различные случаи звездных пятен и пульсаций. Точность орбитальных параметров третьего тела определена для этих случаев. Отделенные затменно-двойные системы с пятном не является сложными объектами для обнаружения 3-го тела. Контактные затменно-двойные системы с мигрирующими пятнами являются более сложным случаем для поиска третьих тел и вычисления их орбитальных параметров. В случае пульсаций затменно-двойной системы более точные параметры орбиты третьего тела могут быть получены при длительном периоде пульсаций. Разрешение кривой блеска очень важна для создания хорошей O-C диаграммы.

Ключевые слова: переменные звезды, затменно-двойные системы, O-C диаграмма, звездные пятна, пульсации.

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ВПЛИВ ПЛЯМ ТА ПУЛЬСАЦІЙ НА ВИЗНАЧЕННЯ ЕЛЕМЕНТІВ ОРБІТИ ТРЕТЬОГО ТІЛА В ЗАТЕМНЮВАНО ПОДВІЙНИХ СИСТЕМАХ

Визначено вплив зоряних плям та пульсацій компонентів затемнювано-подвійних систем на можливість виявлення третього тіла в цих системах та оцінку похибок орбітальних параметрів третього тіла викликаних такими факторами. У цій роботі використано метод O-C діаграм для виявлення зміни періоду затемнювано-подвійних систем, що викликані наявністю третього тіла в системі. Моделювання Монте-Карло були використані для оцінки значень орбітальних параметрів третього тіла, які відповідають отриманим O-C діаграмам. Цей метод закладено в програмне забезпечення «OCFit». В роботі розглядаються різні випадки зоряних плям та пульсацій. Точність орбітальних параметрів третього тіла обчислена для цих випадків. Відокремлені затемнювано-подвійні системи з плямою не є складними об’єктами для виявлення 3-го тіла. Контактні затемнювано-подвійні

системи з мігруючими плямами є більш складними випадками для пошуку третіх тіл та обчислення їх орбітальних параметрів. У випадку пульсацій затемнювано-подвійної системи найточніші параметри орбіти третього тіла можуть бути отримані при тривалому періоді пульсацій. Роздільна здатність кривої блиску є дуже важлива для створення хорошої О-С діаграми.
Ключові слова: змінні зірки, затемнювано-подвійні системи, діаграма О-С, зоряні плями, пульсації.

СПИСОК ВИКОРИСТАНОЇ ЛІТЕРАТУРИ

[1] Prša A. Computational Guide to Physics of Eclipsing Binaries. I. Demonstrations and Perspectives / Prša A., Zwitter T. // The Astrophysical Journal. – 2005. –V. 628. —P.426 – 438.

[2] Wilson R. E. Realization of Accurate Close-Binary Light Curves: Application to MR Cygni / Wilson R. E., Devinney E. J. // The Astrophysical Journal. – 1971. – V. 166. – P. 605.

[3] Irwin J. B. The Determination of a Light-Time Orbit / Irwin J. B. // The Astrophysical Journal. – 1952. –V. 116. –P. 211.

[4] Irwin J. B. Standard light-time curves / Irwin J. B. // The Astrophysical Journal. – 1959. —V. 64. –P. 149.

[5] Gajdoš P. New tool with GUI for fitting OC diagrams / Gajdoš P., Parimucha Š. // Proceedings of the 50th Conference on Variable Stars Research, held November 30 - December 2 2018 in Brno, Ed. R. Kocián, Czech Republic. – 2018. – V. 197. – P. 71.

[6] Kalimeris A. Starspots and photometric noise on observed minus calculated (O-C) diagrams / Kalimeris A., Rovithis-Livaniou H., Rovithis P. // Astronomy&Astrophysics. –2002. – V. 387. –P. 969 – 976.

[7] Barnes J. R. High-resolution Doppler images of the spotted contact binary AE Phe / Barnes J. R., Lister T. A., Hilditch R. W., et.al. // Mon. Not. of the Royal Ast. Soc. – 2004. – V. 348. –P. 1321 – 1331.

[8] Watson C. A. The effect of star-spots on eclipse timings of binary stars/ Watson C. A., Dhillon V. S. // NATO Advanced Science Institutes (ASI) Series C. – 2004. – V. 319. –P. 377.

[9] Hall D. S. Starspot Lifetimes / Hall D. S., Busby M. R. // Proceedings of the NATO Advanced Study Institute on Active Close Binaries, held in Kusadasi, Turkey, September 11-22, 1989. Editor: Cafer Ibanoglu, Publisher: Kluwer Academic Publishers, Dordrecht, The Netherlands, Boston. – 1990. – V. 319. –P. 377.

[10] Guinan E. F. Magnetic Activity in Close Binarie/ Guinan E. F., Giménez A. // ”The Realm of Interacting Binary Stars”. Editor: Sahade, J. and McCluskey, G. E. and Kondo, Y., Publisher: Springer Netherlands. – 1993. –P. 51 – 110.

[11] Berdyugina S. V. Starspots: A Key to the Stellar Dynamo / Berdyugina S. V. // Living Reviews in Solar Physics. – 2005. – V. 2. – Issue 1. – P.62.

[12] Liakos A. A comprehensive study of six Algol type binaries / Liakos A., Zasche P., Niarchos P. // New Astronomy. – 2011. – V. 16. Issue 8. – P.530 – 538.

[13] Roettenbacher R. M. A Study of Differential Rotation on II Pegasi via Photometric Starspot Imaging / Roettenbacher R. M., Harmon R. O., Vutisalchavakul N., et.al. // The Astronomical Journal. – 2011. – V. 141. – N 4. – P.138.

[14] Kővári Z. Measuring differential rotation of the K-giant ζ Andromedae / Kővári Z., Korhonen H., Kriskovics L., et.al. // Astronomy & Astrophysics. – 2012. – V. 539. –P.A50.

[15] Kozhevnikova A. V. Long-term spottedness variations of 16 RS CVn stars/ Kozhevnikova A. V., Alekseev I. Y. // Astronomy Reports. – 2015. – V. 59. – P.937 – 951.

[16] Rucinski S. M. Contact Binaries of the Galactic Disk: Comparison of the Baade's Window and Open Cluster Samples /Rucinski S. M.// The Astronomical Journal. – 1998. – V. 116. –N 6. –P.2998 – 3017.

[17] Maceroni C. The properties of W Ursae Majoris contact binaries: new results and old problems. / Maceroni C., van't Veer., F. // Astronomy & Astrophysics. –1996. – V. 331 – P.523 – 531.

[18] Paczyński B. Eclipsing binaries in the All Sky Automated Survey catalogue / Paczyński B., Szczygieł D. M., Pilecki B., et.al.// Mon. Not. of the Royal Ast. Soc. – 2006. – V. 368. –P. 1311 – 1318.

[19] Lucy L. B. The Structure of Contact Binaries / Lucy L. B. // Astrophysical Journal. – 1968. – V. 151. –P. 1123.

[20] Tran K. The Anticorrelated Nature of the Primary and Secondary Eclipse Timing Variations for the Kepler Contact Binaries / Tran K., Levine A., Rappaport S., et.al. // Astrophysical Journal. –2013. – V. 774. – P. 81.

[21] Maceroni C. Surface imaging of late-type contact binaries I: AE Phoenicis and YY Eridani / Maceroni C., Vilhu O., van't Veer F., et.al. // Astronomy & Astrophysics. –1994. – V. 288. – P.529 – 537.

[22] Hendry P. D. Doppler Imaging of VW Cephei: Distribution and Evolution of Starspots on a Contact Binary / Hendry P. D., Mochnacki S. W. // Astrophysical Journal. – 2000. – V. 531. – P. 467 – 493.

[23] Hussain G. A. J. Starspot lifetimes / Hussain G. A. J. // Astronomische Nachrichten. –2002. – V. 323. –P. 349 – 356.

[24] Rodríguez E. δ Sct-type pulsations in eclipsing binary systems: Y Cam / Rodríguez E., García J. M., Costa V., et al. // Mon. Not. of the Royal Ast. Soc. – 2010. – V. 408. – P. 2149 – 2162.

[25] Liakos A. Catalogue and properties of δ Scuti stars in binaries / Liakos A., Niarchos P. // Mon. Not. of the Royal Ast. Soc. – 2017. – V. 465. – P. 1181 – 1200.

[26] Mkrtichian D. E. The oEA Stars / Mkrtichian D. E., Kim S.-L., Rodríguez E., et al. // "Solar and Stellar Physics Through Eclipses", ASP Conference Series, proceedings of the conference held 27-29 March, 2006 at Ankara University, ÖRSEM Campus, Side, Antalya, Turkey. Edited by O. Demircan, S. O. Selam, and B. Albayrak. San Francisco: Astronomical Society of the Pacific. – 2007. – V. 370. – P.194